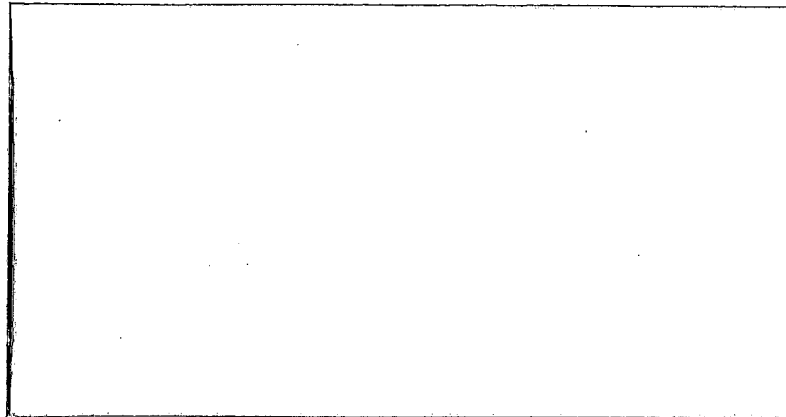


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FINAL REPORT ON SEMINAR
PRESENTATIONS ON THE ECONOMIC
EVALUATION OF THE SPACE
SHUTTLE SYSTEM

prepared for the
National Aeronautics and Space Administration
Washington, D. C.

under Contract NASW-2384

by

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I

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II

INTRODUCTION

This is a final report submitted to the Office of Manned Space Flight of NASA under contract NASW-2384. The purpose of the contract was to present the methodology and results of the Economic Analysis of the Space Shuttle System performed for NASA under the direction of Dr. Oskar Morgenstern, Chairman of the Board of Mathematica, and Dr. Klaus P. Heiss, Director of Advanced Technology Economics.

This report describes the presentations given and some of the responses achieved. The following seminars were given by members of Mathematica's staff during the duration of the contract:

Dr. Oskar Morgenstern: at Sandia Corporation, March 23, 1972; at the University of New Mexico, March 24, 1972; the School of Naval Architects, Long Island, November 4, 1972; the Naval Ordnance Laboratory, White Oak, Silver Springs, Maryland, November 10, 1972; and Carnegie Mellon University, Pittsburgh, Pennsylvania, October, 1972.

Dr. Klaus P. Hiess: at the University of California at Berkeley, April 3, 1972; the Rand Corporation, Santa Monica, California, April 4, 1972; the University of California at Los Angeles (UCLA), April 7, 1972; and Princeton University, Princeton, May 1, 1972.

Dr. Uwe Reinhardt and Dr. Klaus P. Heiss: at the National Association of Business Economists, Southern California Chapter, June 1, 1972; the University of Southern California, San Diego, June 2, 1972; and the Goddard Space Flight Center, September, 1972.

Dr. Uwe Reinhardt: at the Boeing Aircraft Corporation, Seattle, Washington, November 3, 1972.

Dr. Morgenstern and Dr. Heiss: at New York University,
April, 1972.

Overall 14 formal seminars were held.

In addition more informal presentations were given by members of Mathematica's staff at various occasions, but not under this contract. These include, among others, the Office of Naval Research (Dr. Oskar Morgenstern), the International Astronautics Federation (Dr. Klaus Heiss) and John Hopkins University (Dr. Oskar Morgenstern).

A detailed report on the most important presentations follows.

Sandia Laboratories, March 23, 1972

University of Mexico, March 24, 1972

Organized by W. G. Corgan, Sandia Corporation

Attendance: over 100 people, engineers, analysts, managers.

On March 23rd, Dr. Oskar Morgenstern presented the analysis of the Space Shuttle undertaken by Mathematica in the "Blue Report". The attendance was about 100 persons, all highly qualified engineers, analysts, and mathematicians, and members of the staff of the laboratories.

The presentation lasted about one hour and covered the usual matters which are essentially summarized in the Executive Summary. The attention was excellent; many people took copious notes and afterwards there was a long question period. The questions mostly were for amplification of particular points, to increase the state of information. There was no hostile or critical factors of any kind. Yet, on the other hand, it was clear that the listeners were not very well informed about the Shuttle. They only had read about it in the papers. Except that one element appeared, namely that New Mexico is eager to get one of the possible launching sites, but it was agreed that this was a political question, namely the location of the Western launching site, which had little to do with the Mathematica analysis. Dr. Morgenstern admitted, however, that it would be possible to analyze even this question economically, from a point of view of already existing launch sites, minimizing pollution, noise, available personnel, unemployment and so forth. However, all this was outside the presentation's subject matter.

The entire discussion, as well as Dr. Morgenstern's presentation, was taken down on tape. Xerox copies were made of the slides shown because a large number of persons were prevented for various reasons from attending and wanted to hear what Dr. Morgenstern had to say.

One point worth mentioning was that a person whom Dr. Morgenstern could not identify otherwise asked why in view of the fact that the total investment is not phenomenally large, private industry would not simply start the Shuttle, and run it under government supervision. Dr. Morgenstern answered that this would be difficult for various reasons, but it would appear to him that the establishment of a mixed government-and-privately owned corporation which would construct and run the Shuttle is something seriously to be investigated. Dr. Morgenstern mentioned that, for example, investments of several billion dollars over many years is not an unheard magnitude, for example for the oil industry. In fact, it occurred to Dr. Morgenstern that one might even open this next corporation to international organizations or European ones, Japanese perhaps. This is something one ought to think about.

On the following day, Dr. Morgenstern spoke at the University of New Mexico on a variety of topics and Shuttle questions came up also and Dr. Morgenstern discussed them, though not in that detail as at Sandia Laboratories before the economists of the University. The interest was again considerable. Every where the upshot is that the study is considered to be a significant contribution to the analysis and justification of large scale public investment projects.

New York University, April, 1972
Department of Economics
Graduate School of Arts and Sciences
Organized by Professor M. I. Nadiri

Attendance: 45 people, graduate students and faculty.

Dr. Oskar Morgenstern and Dr. Klaus Heiss gave the presentation of the economic analysis of the Space Shuttle System. The seminar concentrated on the problems of economic analysis of large scale public investments, the state of the art of cost estimation, the statistical data base for estimating costs of new technological systems and the role of the main economic parameters affecting the results of such analyses. Among the issues discussed were the influence and the level of the social rate of interest, the activity and budget levels of space activities in the 1980's versus the 1960's, the meaning and magnitude of payload effects, the size of risk and uncertainty and alternative approaches to their quantification and measurement.

The presentation lasted for two hours and the discussion extended beyond the usual seminar time. The student and faculty body were generally unaware of the scope and depth of analysis carried out on the Space Shuttle System. The credibility of the analysis was agreed to be good and outstanding. One question raised was whether the same method of analysis was being extended to other technology programs of government and industry. Also, the question was raised, on how the SST would have done with a similarly strict economic analysis approach. Several topics for further research were raised and the reception by the group was excellent.

University of California - Berkeley

Economics Department

Graduate School Seminar - April 3, 1972

Directed by Dr. George F. Break, Dr. Fischer

Attendance: 35 people, Economics and Engineering Department
(Operations Research Group under Dr. Ronald Shephard)

This session was of particular interest since the Chairman of the Industrial Engineering and Operations Research Department at the Engineering School, Dr. Ronald Shephard had directly participated in the theoretical work underlying the Economic Analysis of the Space Shuttle System.

For this reason the presentation by Dr. Klaus Heiss was rather advanced and emphasized theoretical questions and problems, after giving a brief survey of the approach and the results of the economic analysis of the Space Shuttle System. The practical implementation of some advanced concepts in economic theory greatly stimulated the discussion. It was one of the few presentations, to the recollection of Dr. Ronald Shephard, where concepts of operations research and economic theory were implemented with such imagination and consistency. The ensuing results of the economic analysis were generally accepted as valid, although surprising. The presentation proceeded as follows:

1. General Theoretic Framework of Analysis. In the economic analysis Mathematica distinguished between benefit-cost and cost-effectiveness analyses. In Ronald Shephard's framework, within the evaluation of a single

technology, the distinction of the two analyses can be strictly reduced to effectiveness analyses. In this the Mathematica analyses and Ronald Shephard's work on the theory of cost and production functions agreed. The same result can be obtained when more than one technology are compared.

2. The equal capability analysis and "return afforded input" correspondences. The equivalence of the equal capability analyses and the return afforded output correspondences were proven.

3. The equal budget analysis and "cost limited output correspondences." Again the equivalence between the two analyses was proven.

The larger issue of benefit estimation versus cost effectiveness analyses was raised by Dr. Heiss. The issue becomes important when the added outputs of the "cost limited output" correspondences noticeably change price and supply parameters which in turn should affect total market equilibrium demand. This issue is left open in the theory of production and cost functions, but does seriously arise in the context of projects of a scale like the Space Shuttle System where one can no longer maintain the fiction of independence of macro-economic effects from the results of single project evaluations. The Space Shuttle itself will have noticeable effects on prices and potential supply of space transportation capabilities on a national scale. Also, the size of investment resources required for the development of the Space Shuttle is most definitely of macro-economic consequences. Dr. Heiss explained how each of these additional issues was dealt with in the analysis and problems that remain open.

The RAND Corporation

Santa Monica, California, April 4, 1972

Economic Analysis and Cost Effectiveness Group

Organized by Dr. R. D. Shaver

Attendance: 20 people (economists, cost analysts). Also attending Lou Mogavero, NASA Headquarters.

In view of RAND's economic analysis of the Space Shuttle of October, 1970, ("The Space Shuttle As An Element in the National Space Program", by R. D. Shaver, D. J. Dreyfus, W. D. Gosch, and G. S. Levenson) the session at RAND Corporation promised to be of particular interest to the study group and to NASA. Yet, after the full presentations were made, the agreement on our approach and findings was so complete, that to Dr. Heiss' surprise hardly any "adversary" discussion followed. R. D. Shaver acknowledged in a letter to Dr. Heiss the complete agreement of him and his staff with the work done by Mathematica.

The presentation itself was a review of the summary findings of the analysis by Mathematica. The presentation emphasized:

1. The overall economic justification of the Space Shuttle System within the over 100 space programs (scenarios) analyzed.
2. That the Space Shuttle investment could not be justified economically only in terms of transportation cost savings.
3. The importance and magnitude of payload effects. RAND participants pointed out the scarcity of "payload effects" data existing at the time of their analysis (1970).

4. The identification of the most economic Space Shuttle System among the many alternative configurations considered. In subsequent private discussions participants confirmed their strong agreement with the SRM-TAOS configuration which now is being developed by NASA.

5. The importance and impact of the social rate of discount in the economic analysis.

6. The measurement of risk and cost uncertainties in the economic analysis.

As mentioned above, there apparently exists considerable agreement among RAND analysts on the findings and methods used in the Mathematica analysis. This should lay to rest any possible disagreement that might have existed prior to this meeting, if any existed.

University of California, Los Angeles
Economics Department, April 5, 1972
Directed by Professor Clayburn La Force

Attendance: 20 people, students and faculty. Also present,
Mr. Lou Mogavero, NASA Headquarters.

At this presentation of the Economic Analysis of the Space Shuttle System it became quite apparent that there exists a wide and general lack of understanding in the economic community, and public, of the operations of space programs, its cost components, its objectives, and the many different activity levels among NASA, other civilian applications and military applications. The presentation, given by Dr. Klaus Heiss, had to concentrate heavily on the explanation of the system components of a space program, the present choice of launch vehicles, spacecrafts and instrumentation; only then the context of the Space Shuttle economic analysis could be intelligibly explained to this student/faculty body.

In the presentation the issues of most immediate interest were:

1. The measurement of benefits in projects like the Space Shuttle System. Equal capability and equal budget analyses were explained as well as the "scenario" approach to estimating space activities of the 1980's.
2. Techniques of cost estimation: the cost estimating relationships (CER's), the statistical basis for such estimates, and the difficulty of comparable cost data at a subsystem level were explained.
3. The identification and choice of investment alternatives: the current expendable system, the new expendable system and the Space Shuttle System were defined as the major investment alternatives.

Dr. Heiss explained in detail the economic tradeoff function between short term non-recurring costs and long term recurring cost savings.

4. The importance of the social rate of interest in the evaluation of investment alternatives. The impact was demonstrated with the example of the Space Shuttle evaluation. The relative importance of cost uncertainties, of payload effects and the IOC date were shown based on the findings of the Summary of the Economic Analysis.

In general the faculty, as well as student body, were not aware of the extent and the depth of economic analysis performed on the Space Shuttle System. In the discussion useful extensions of the techniques used in the analysis to other technological investment project analyses were explored. Also, the issue was raised on whether the Space Shuttle System might not be developed with private initiative and/or participation. In response to the latter issue it was noted that due to the defense applications of any Space Transportation System a valid "public good" case existed which, a priori, would indicate a strong case for the government to develop and finance new space transportation systems.

Princeton University, May 1, 1972

Economics Department

Directed by Professor D. M. Jaffee

Attendance: Faculty and Students, about 25 people.

Dr. Jaffee organized a discussion of the Economic Analysis of the Space Shuttle within the graduate economics program of Princeton University. Dr. Klaus Heiss gave a 60 minute presentation of the economic approach used in the analysis. The emphasis in the presentation was on (1) the method of measuring benefits for large scale investment projects in pursuit of national goals, (2) the equal capability and equal budget analyses performed and their implications, (3) the evaluation of risk and cost uncertainties and (4) the role and level of the social rate of interest.

In the discussion several questions with regard to equal capability and equal budget analyses were raised. Dr. Heiss explained the "scenario" approach to estimating space activity levels in the 1980's and the generally conservative budget levels implied by the "baseline" and "modified baseline" models.

The overall importance and impact of different levels of the social rate of interest was surprising to some participants. The discussion centered on the divergent methods of estimating the true level of the social rate of interest and its change over time. Dr. Heiss pointed out the basic inconsistency between the results of Von Neumann, showing the equality of rates of growth and real interest rates in closed, linear economic systems, and alternate explanations of the level of the social interest rate, e. g.,

time preferences of a society, or the opportunity cost of capital goods in the private sector. Generally, the participants agreed that the 10 percent real interest rate used for the basic findings of the study was high and that the true level of the social rate of interest lay probably between 4 and 10 percent.

National Association of Business Economists
Southern California Chapter, June 1, 1972
Ambassador Hotel, Los Angeles, California
Directed by C. W. Murphy, President

Attendance: 35 people, (North American Rockwell, Lockheed Corporation, Aerospace Corporation, Department of Defense, SAMSO, Economic Research Associates).

Drs. Klaus Heiss and Uwe Reinhardt gave a one day presentation and discussion of the economic analysis of the Space Shuttle System.

The morning session consisted of a two hour presentation of the complete economic analysis of the Space Shuttle System performed in 1970-1971 ("Red Reports") and 1971-1972 (January, 1972 publication). In the presentation the following major topics were discussed:

1. The objectives of space transportation in the 1980's when compared to the historical activities of the United States and the Soviet Union in the 1960's and early 1970's. The baseline mission model was fully presented, as well as the spacecraft and payloads work, at a subsystem level, performed by LMSC and Aerospace Corporation in support of the Mathematica studies.

2. The three alternative space transportation systems analyzed, namely the current expendable, the new expendable and the Space Shuttle and Tug Systems.

3. The equal capability and equal budget analyses performed on the baseline mission model. The different benefit implications of the two

approaches were highlighted and Dr. Heiss pointed out that the basic findings of the study relied on the equal capability analysis.

4. The estimation of future levels of space activity and the "scenario" approach. The cost distribution of all payload classes were shown for the three different space transportation systems. The method of creating and analyzing additional space programs was discussed in depth. Overall, more than 100 space program alternatives were costed out and evaluated as to their impact on the economics of the Space Shuttle and Tug System.

5. Payload effects. The importance of the cost impact of the Space Shuttle System on spacecraft instrumentation and mode of space program operations was illustrated in three specific payload programs. The generalization of payload effects across the mission model and the support studies existing on a subsystem basis were presented. Also, the effects of standardization and reliability were pointed out as further possible payoffs of the Space Shuttle System that were not yet adequately included in the benefit measure of the Space Shuttle System.

6. Alternative Space Shuttle Systems identification and evaluation. The range of Space Shuttle System alternatives were listed ranging from two stage fully reusable shuttles, flyback booster shuttles, series burn expendable booster versions, to parallel burn pressure fed and SRM boosters as well as space glider concepts and the new expendable family. The non-recurring versus recurring cost tradeoff line and its impact on the selection of the most economic Space Shuttle configuration (twin SRM Space Shuttle) was explained.

Dr. Uwe Reinhardt gave the luncheon speech. The topic was on the interaction of economic sciences and technological change as exemplified in the Space Shuttle Systems analysis, as well as in private ventures such as the DC-10 and L-1011. The consequences of correct versus faulty economic analyses of investment alternatives, their costs and risks were illustrated with specific case studies.

In the afternoon session the discussion was opened to include topics of immediate interest to the participants in the meeting. It was generally agreed that the tools used in the analysis of the Space Shuttle System could be readily used in decisions of comparable nature in defense, government, as well as private ventures.

Carnegie Mellon University, October, 1972
Graduate School of Industrial Administration
Pittsburgh, Pennsylvania

Directed by Dr. Norman Miller and Dr. Gerald Thompson

Attendance: 30 people, graduate students and faculty.

Dr. Oskar Morgenstern gave a presentation of the economics of the Space Shuttle System within the Graduate Seminar of the Industrial Administration Department. Dr. Gerald Thompson directed the seminar.

The presentation followed the usual format established in the previous presentations. Of particular interest were the cost estimation techniques, risk and uncertainty and the "management" concept implied in the cost estimates submitted.

The fact of historical cost overruns and the general inaccuracy of economic observations were discussed. Dr. Morgenstern pointed out the framework of cost uncertainty simulations performed within the economic analysis of the Space Shuttle System. The other major economic parameters, the social rate of interest, the space activity and budget levels implied by the space programs of the 1980's, the gestation period and the IOC date, were illustrated with quantitative examples drawn from the economic analysis.

In conclusion, Dr. Morgenstern observed that the level of information on the scope and problems of space activity was very low. Apparently the opportunities of space applications, exploration and transportation were not quite understood, nor adequately explained to them before this seminar.

Boeing Corporation

Seattle, Washington

Economic Analysis Group, November 3, 1972

Attendance: 25 people.

Dr. Uwe Reinhardt gave a one day presentation of the economic analysis of the Space Shuttle System. In the workshop the following problems and topics were emphasized:

1. The overriding importance of the level of the social rate of interest on the economic evaluation of investment alternatives. Examples from the aerospace industry, other than the Space Shuttle, were also analyzed (L-1011, 747, DC-10). The severe implications of any slippage in the IOC date of major new systems, of cost uncertainties and development risks and of the expected demand for the technology developed were each shown as to their effects on the economic evaluation of the Space Shuttle System.

2. The cost per flight of the Space Shuttle. While expendable Space Transportation Systems allow a rather straight forward approach to the costing and pricing of individual flights and their influence on the charges for each payload (basically 1:1), the Space Shuttle System poses entirely new problems. The average costs of Space Shuttle flights has to be distinguished from the incremental Space Shuttle flight costs in each year and over different years. Furthermore, given the capability of the Space Shuttle to deliver more than one payload per flight, problems of joint production and allocation of costs arise that are novel to NASA and the space transportation community. The optimum pricing of Space Shuttle flights remains an important and still unresolved issue.

3. The equal capability and equal budget analysis approach.

Each was described in detail and their implication as to the magnitude of economic benefits attributed to the Space Shuttle System.

The subsequent discussion was very interesting and involved a whole range of economic analysis problems particular to a company in the aerospace field.

Naval Ordnance Laboratory

White Oak, Silver Springs, Maryland

Applied Mathematics Seminar (Code 331) November 10, 1972

Directed by Dr. Julius Enig

Attendance: 25 people.

The presentation by Dr. Oskar Morgenstern followed the same format as the earlier presentation to Sandia Corporation. In the discussion two topics of particular interest were raised:

1. The problem of the "Non-Archemidian Property" of some new technological systems. The Non-Archemidian Property implies that the difference in the capabilities of the new versus the existing technology is such that the properties of the new technology cannot be equalled by any number of iterations or quantitative additions to the capabilities of the existing technology; e. g., some capabilities of nuclear submarines are unique to nuclear submarines and are simply not "reachable" by conventional submarines, however large their number may be (duration of submersion, reach, etc.). In such cases particular problems arise in the application of analytic economic tools to R&D investment decisions.

Dr. Morgenstern pointed out the implied conservation of the equal capability and the equal budget approaches in light of the above issue.

2. Cost estimation, cost control, and cost uncertainties. The concept of allowable non-recurring costs as a measure of "benefits" directly comparable to the estimated non-recurring costs was explained. The basic stochastic (probalistic) nature of costs and cost estimates was discussed. The cost distributions arrived at by the Monte Carlo simulation of the Space Shuttle life cycle cost streams was illustrated.